

A Systems Thinking Approach to the Traffic Congestion in Singapore, and its Economic Cost

Kenny Liew Sim Hoong, *National University of Singapore*

Abstract

Traffic congestion presents itself as an economic endemic particularly in urbanized areas and central business districts (CBDs) of a country. This problem holds especially true for Singapore, which is fully-urbanized, and constantly suffers from traffic congestion daily. Time spent in traffic jams, delays, and emissions from vehicles all present themselves as major costs to Singapore's economy. This paper provides a systems analysis to estimate travel times to Singapore's CBD with congestion and to give a deep insight of Singapore's traffic problem. It will also estimate economic losses, such as time wastage and vehicle emissions due to traffic jams. Results of the study will be compared and contrasted to studies run in other countries, such as the United States and the United Kingdom to assess the severity of the problem to Singapore. Recommendations to improve traffic flow are presented next and implemented to the traffic congestion model – and from a systems thinking and economics perspective, validated and analysed.

Note:

This paper is intended as an academic exercise, and provides a comprehensive coverage of Singapore's traffic situation, and systems thinking and dynamics through the understanding of an Economics undergraduate. This is a suitable reading for those with little to no knowledge of Singapore or of systems dynamics.

1. INTRODUCTION – Defining concepts and terminology, and a background to the seriousness of traffic congestion

1.1 Defining *traffic congestion*

In simplest terms, traffic congestion will be defined where progress or movement is impeded by interaction between one vehicle and other vehicles, caused when demand for road space approaches the capacity. Traffic congestion can also be defined to occur when average travelling speeds are equal to or less than 70% of free flow speeds (i.e. speed limits). For instance, congestion is said to be occurring on a road where average speeds of all vehicles are 28km/h or below, whereas the speed limit of the road is 40 km/h. Other circumstances, such as bad weather or unforeseen infrastructure collapse (e.g. bridge collapses, lamp-posts falling), also impact traffic flow, although, at least to Singapore's context, are infrequent¹.

When traffic congestion occurs as per the definitions above, the effects of congestion are typically characterised by:

- Longer and less predictable journey times
- More time spent stationary (not moving)
- Increased queues at road branches and junctions
- Increased stopping and starting

¹ Singapore's road infrastructure quality ranks 6th in the world, ahead of developed countries like the U.S. and

Germany (World Economic Forum Global Competitiveness Report 2014)

1.2 Defining *economic costs*

Idling and moving slowly in traffic incurs various costs to the road user(s), as well as to the economy. To provide a perspective of what is meant by *costs* and specifically, *economic costs*; the following list includes, but does not limit, the examples of *costs* and *economic costs*:

- Time lost – Time spent in traffic occurs at the expense of time spent contributing towards economic growth. Besides that, congestion reduces the ability to predict journey times. More time is spent planning for a journey, and arriving too early/late for appointments increase time lost.
- Vehicle operating costs – Increased usage of vehicles increases wear and tear, incurring higher operation costs, which include maintenance and fuel, among other costs
- Pollution costs – Idling in traffic in general increases carbon emissions of the vehicle, which leads to pollution which will affect factor productivity of the economy (for instance, increased carbon emissions leads to higher likelihood of sickness, reducing productivity of labour)
- Safety costs – Time spent idling in and on the road increases the likelihood of traffic accidents. Costs include time processing insurance claims, cost of repairs, cost of medical bills

As a result, traffic congestion carries large and severe economic implications, viewed through the lenses of systems thinking in this paper.

1.3 Quantifying *economic costs*

The above costs all affect Singapore's economy directly. To quantify the extent of the loss, this paper will utilize Gross Domestic Product (GDP) as the measure of economic value lost. GDP, put technically, is the annual monetary value (in Singapore Dollars (SGD)) of all goods and services produced within Singapore's borders. In more basic terms, it is total economic output generated in Singapore. Other measures of economic cost exist, such as factor productivity loss, however are rather complex to be quantified and a full model on productivity loss is well beyond the scope of this paper.

Other terms will be explained when introduced at the different sections in the paper.

1.4 What Causes Traffic Congestion?

A myriad of factors explain increased congestion in a particular area:

1) Trip Clusters

This is the factor that causes concentration of vehicles to increase at particular times. It is noted that vehicle congestion in Singapore is heaviest during the periods of 8a.m. – 9a.m. and 5p.m. – 6p.m. Trips cluster in this way because many organizations start and end their work days at the same time.

Simultaneously, schooling hours in Singapore begin at 8a.m. This is characterized by increased school bus volume ², alongside private cars and motorcycles, further contributing to the AM peak congestion.

2) Ignored Spill Over Effects

Motorists who use their vehicles only need to bear two direct costs: time lost and vehicle operating costs. These can be classified as

² There were 1845 school buses registered in 2014, and many private hire buses are also used by schools.

private costs, while pollution and safety costs can be called public costs³. By commuting during peak hours, commuters not only increase the time they spend in a gridlock, but also the marginal time spent by everybody else on the road. As long as the benefits of commuting exceed the private costs, commuters will continue to commute, completely ignoring the costs imposed to society.

This is the crux of the issue. Economic theory dictates that individuals will choose to do something when benefits exceed the cost. Key methods of reducing congestion will be discussed later, and a majority of them involve increasing the cost of commuting for a road user.

3) Rapid Population and Job Growth

Recent rapid population growth due to globalization and economic expansion has contributed to increased congestion in many countries. However, Singapore has been facing a congestion problem as early as 40 years ago, even when it had a less than dense population. In 1975, its car population per capita was highest in the world. However, vehicle usage restraint measures⁴ put into place by the government since has seen adjustments of the car population to be more proportional to its population and road network growth.

4) Desire to Travel in Private Vehicles

Private vehicles offer many benefits, including convenience, comfort and privacy. In Singapore, owning a private vehicle (mostly a car) is heavily linked to social status, with many Singaporeans aspiring to own a car as a status of their prosperity and wealth⁵. Growing economic affluence has seen a high demand of cars. However, Singapore's vehicle population is limited by a quota called the Certificate of Entitlement (COE) system, explained in Section 2.3.

1.5 How Costly is Traffic Congestion?

Traffic congestion is a costly problem to every economy, regardless of scale. Sterman (2000) quotes several numbers of cost of traffic congestion to the United States – the estimated loss of economic value as a result of traffic jams ranges from USD43 to USD168 billion annually⁶. The Texas A&M Transportation Institute reports losses of USD160 billion to the United States in the year 2014, with congestion cost per auto consumer of USD960 – a pronounced increase from the USD42 billion estimated in 1982⁷.

In the United Kingdom, studies indicate annual losses of £4.3billion per year due to traffic congestion⁸, with an estimated £21.4billion in the year 2030⁹.

No studies exist for Singapore as of yet, and this paper aims to estimate this number by presenting

³ Economists call these public and private externalities

⁴ The Singapore government implemented the Area Licensing Scheme in 1975 to reduce congestion in the CBD during peak hours.

⁵ Rappa, Antonio L. 2002. *Modernity & Consumption*. Singapore: World Scientific.

⁶ Sterman, John. 2000. *Business Dynamics*. Boston: Irwin/McGraw-Hill.

⁷ Schrank, David, Bill Eisele, Tim Lomax, and Jim Bak. 2015. '2015 Urban Mobility Scorecard'.

⁸ Telegraph.co.uk. 2012. 'Traffic Congestion Costs UK Economy £4.3Bn A Year'. <http://www.telegraph.co.uk/finance/newsbysector/transport/9734126/Traffic-congestion-costs-UK-economy-4.3bn-a-year.html>

⁹ INRIX. 2015. 'Traffic Congestion To Cost The UK Economy More Than £300 Billion Over The Next 16 Years - INRIX'. Accessed November 6. <http://inrix.com/press/traffic-congestion-to-cost-the-uk-economy-more-than-300-billion-over-the-next-16-years/>.

a vehicle and economic population model, constructed through systems modelling.

2. SINGAPORE IN NUMBERS

The following are some salient numbers and statistics regarding Singapore, and of interest to the study:

2.1 Geography & Demographics

Singapore is a small island-state situated south to the Malaysian peninsula, and features a land area of 718.3 km². It is 50 kilometres (31 miles) wide and 26 kilometres (16 miles) measured north to south. The country has a population of 5.46 million, and is slated to increase up to 6.9 million by 2030, through growing the labour force and the student population¹⁰. About 82% of Singaporeans live in high-rise public housing¹¹, leading to townships and housing estates with high population density.

2.2 Road Length

Singapore features relatively dense road networks per unit area, standing at almost 4.5km/km² compared to other countries of similar geographic circumstances, such as Hong Kong which has a density of about 1.76 km/km². London and New York both feature densities of about 13 km/km² and 18.5 km/km² respectively. Roads in Singapore span up to a total of 3,496 kilometres as of 2014, and over the past 10 years, road development and extension has grown by a mere 8%, from 3,234 kilometres in 2005.

However, the statistic of interest is the length of *road-lane kilometres*, which is the total length of road lanes. For instance, a 3-lane highway which has a distance of 10 kilometres will have a road-lane kilometre count of 30km. This statistic is of

interest as it shows the total usable road length for vehicles. For Singapore, this statistic amounts to 9232 kilometres.

It shall be noted that these statistics exclude private roads, as well as roads built within hospital compounds, roads within HDB (Housing Development Board) areas, which are road built within government provided housing, roads within military (Ministry of Defence) areas and airport roads. This paper will ignore these roads, as they are (largely) infrequently used by public vehicles and suffer from little to no congestion, and has little effect on the final results of this paper.

2.3 Vehicle Ownership

Vehicle ownership in Singapore is tightly controlled and regulated by the Land Transport Authority (LTA). To possess a vehicle in Singapore, one must first bid for a Certificate of Entitlement (COE), which allows the owner possession of vehicle for 10 years, after which the vehicle must be scrapped or the COE must be renewed at prevailing renewal rates.

The number of COEs in each bidding round is arbitrarily regulated by the LTA. COEs are further divided into 5 categories as follows. The distribution of COEs by category is determined by the LTA, and the distribution between categories is not defined by any formula.

The listing of COE categories:

Category A	Cars with engine capacity 1600cc and 130 hp and below
Category B	Cars with engine capacity exceeding 1600 cc or 130 hp
Category C	Goods carrying vehicles and buses
Category D	Motorcycles

¹⁰ National Population and Talent Division., 2013. A Sustainable Population For A Dynamic Singapore:

¹¹ Department of Statistics Singapore., 2015. Population Trends 2014. Ministry of Trade & Industry

Category E	Open category (can be used for all the above)
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Table 1: COE Categories

Successful bids for the COE are determined by the lowest successful price clearing system. This system can be illustrated by the following simple example. Assume that there are 4 bidders for COEs in the current bidding round, and the COE quota is only 3.

Bidder Number	Bid
1	SGD 100,000
2	SGD 80,000
3	SGD 70,000
4	SGD 60,000

Table 2: Example of hypothetical bidders

The three highest bidders will secure the COEs, with the trio only paying SGD 70,000 (the lowest successful bid). The fourth bidder is unsuccessful as there are only 3 COEs up for auction.

The formula for issuing COEs in every quota year is determined by the LTA using the following formula:

$$\begin{aligned}
 &(\text{Total COE Quota})_{qy} \\
 &= g \cdot (\text{Motor vehicle registrations})_{y-1} \\
 &+ (\text{Projected deregistrations})_y \\
 &+ (\text{Unallocated quota})_{qy-1}
 \end{aligned}$$

Where:

- g = growth rate determined by the LTA.
- Prior to 2009, growth rate was 3%
 - 1.5% (2009 – August 2012)
 - 1% (August 2012 – February 2013)
 - 0.5% (February 2013 – January 2015)
 - 0.25% (February 2015 onward) ¹²
- y = current year
- qy = COE quota year

We can observe from the formula that the total COE quota for a given quota year is largely determined by the first term in the equation, the number of motor vehicle registrations in the previous calendar year multiplied by the growth rate g (which averages at about 1.5% a year, as mentioned earlier), causing supply of COEs to be arbitrarily limited. This has regularly led to extremely inflated prices as demand necessarily exceeds supply - prices of the COE for private cars have averaged at SGD 70,748.50 in the year 2014.

It must be noted that the growth rate of motor vehicle population throughout the past 10 years (2005 – 2014) has been higher than the growth rate of roads. While as mentioned earlier that road length has grown 8%, the motor vehicle population has grown 28%, from 754,992 vehicles to 972,037. Car population alone has grown 40.71%. Put roughly, this means that the number of vehicles has increased at a greater rate than the capacity of roads.

2.4 Economy

Singapore is one of the most affluent countries in the world, and boasts a Gross Domestic Product (GDP) of SGD 390 billion (SGD 390,000,000,000) in 2014, which equates to a GDP per capita of SGD 71317.90 – the third highest in the world, behind Qatar and Luxembourg. Put very roughly, the GDP per capita can be understood as the amount of income an average Singapore resident earns annually. The currency of exchange in Singapore is the Singapore Dollar (SGD). One United States Dollar (USD1.00) is roughly equivalent to SGD1.42.

Singapore's economy is heavily trade-reliant, which major industries include export of electronics and chemicals, as well as services. A majority of Singapore's economic output is

¹² Lta.gov.sg. 2015. 'Vehicle Quota System | Owning A Vehicle | Roads & Motoring | Land Transport Authority'. Accessed November 6.

<http://www.lta.gov.sg/content/ltaweb/en/roads-and-motoring/owning-a-vehicle/vehicle-quota-system.html>

produced in its Central Region – a 131.5km² area located in the south of Singapore.



Figure 1: The Central Region of Singapore

2.5 Summary of Statistics

A table of all statistics is presented below, alongside comparisons with Hong Kong, a city-state which draws many similarities with Singapore.

STATISTIC	Singapore (2014)	Hong Kong (2014)
General Statistics		
Population	5.4697 million	7.2665 million
Land area	718.3 km ²	1104.0km ²
Population density	7614.78 people/km ²	6581.97 people/km ²
Road Statistics		
Road length	3234 km	1944 km
Road-lane kilometres	9232 km	N/A
Road density	4.5km/km ²	1.76 km/km ²
10-year growth rate of roads	0.8%	
Vehicle Ownership Statistics		
Motor Vehicle Ownership	972,037 vehicles	769,199 vehicles
Taxis	28,736 taxis	---
Economic Statistics		
Gross Domestic Product (GDP)	SGD 390 billion	SGD 413 billion
GDP Per Capita	SGD 71317.90	SGD54396.54

Sources: Land Transport Authority (Singapore), Census and Statistics Department (Hong Kong)

Table 3: Summary statistics of Singapore and Hong Kong

2.6 Why Singapore?

The traffic congestion problem is amplified for a country the size of Singapore – a tiny little island, the “little red dot”. With 12% of Singapore’s land already taken up by roads and limited room for expansion¹³ – and the added fact that Singapore is intending to grow its population to 6.9 million by

2030, Singapore needs to manage its traffic situation effectively and efficiently.

The problem of congestion in Singapore also dates long back, up to 1975, with recorded average vehicular speeds of around 19 km/h during peak hours¹⁴. Although the magnitude of congestion has reduced over the years, Singapore still suffers

¹³ Land Transport Authority, 2013. Land Transport Master Plan 2013. Singapore.

¹⁴ Phang Sock-Yong and Toh Rex S., 1997 From manual to electronic road congestion pricing: the Singapore experience and experiment, Vol 33. No 2, Logistics and Transportation Review

from congestion – just like many other major economies, given a growing population, both in numbers and in affluence.

Singapore, which is linked to Malaysia via a 1 kilometre bridge, also sees a large flow of traffic to and from Malaysia during rush hours. Singapore controls growth rate of its traffic population via the COE system, as described earlier, but the inflow of vehicles from Malaysia is only controlled by the Vehicle Entrance Permit (VEP) fee, a toll-charge on foreign-registered vehicles upon entry to Singapore. No limit is placed on the number of vehicles allowed to enter. This further imposes

limitations for Singapore to control its vehicle population on a day-to-day basis.

Singapore's experimentations with congestion reduction schemes, such as the weekend car (WEC) and off-peak car (OPC) scheme has seen mixed results. As Singapore tries to find solutions to its traffic problem, this paper will also provide a model for it to predict and measure the feasibility of its solutions. Major advancements in technology has also allowed solutions, such as autonomous driving vehicles to be analysed and implemented.

3. ECONOMIC LOSS DUE TO TRAFFIC CONGESTION

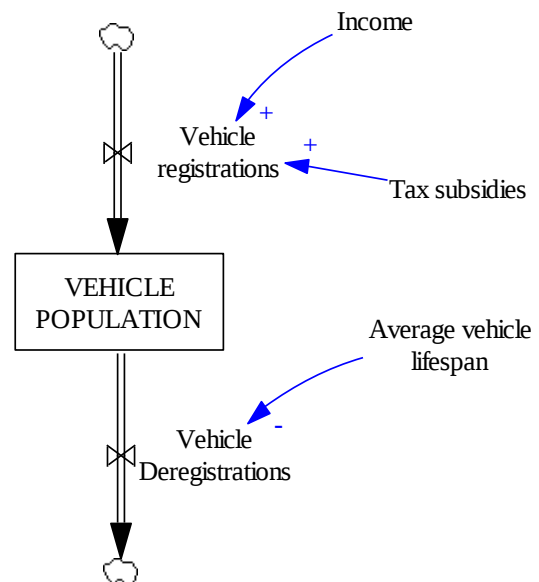
This section will determine the economic loss of congestion. It will begin by providing a simple exercise to systems modelling by producing a model of Singapore's car population and predicted vehicle growth rates (Section 3.1).

Section 3.2 will determine the additional travel time resulting from congestion by looking at the various factors that determine a person's decision to commute, and frequency of vehicle trips per day.

Section 3.3 will model Singapore's population and economy. Section 3.4 will calculate losses as a result of additional time spent in congestion, as well as fuel and economic costs. Section 3.5 sums up all these costs, Section 3.6 provides a conclusion and Section 3.7 discusses some limitations of the modelling carried out.

3.1 The Singapore Vehicle Ownership Model

We start by illustrating a simple vehicle ownership model:



Model 1: Simple Vehicle Population Model

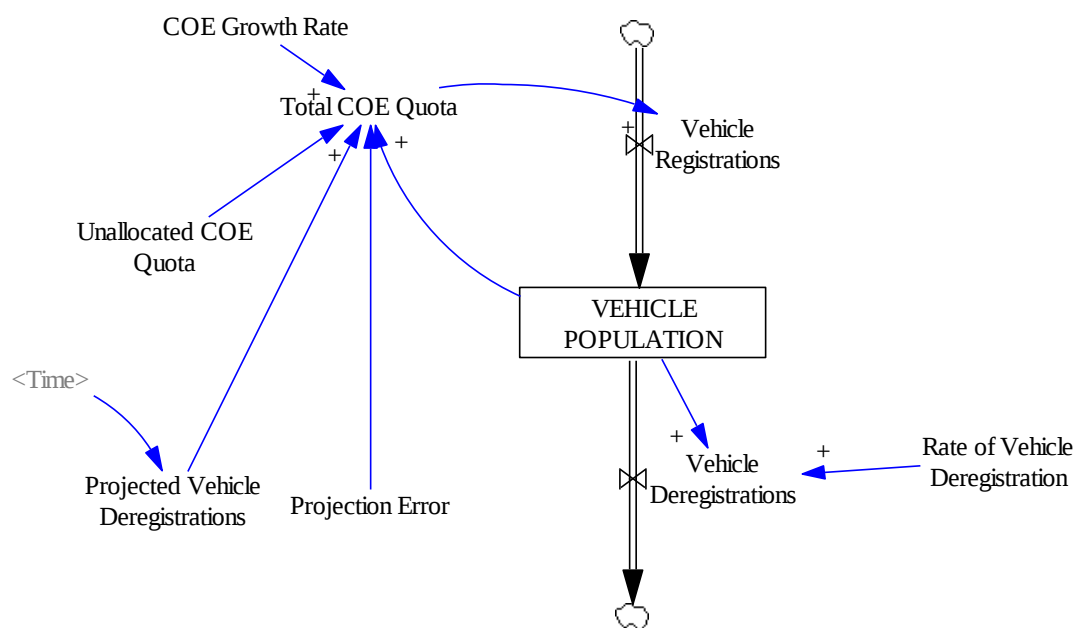
What would normally increase new vehicle purchases and registrations would be income and tax subsidies (i.e. price of the vehicle). Many would also normally keep their vehicle for its lifespan, while some will sell the vehicle before the end of its lifespan.

However, Singapore's car ownership model is unique in the fact that it is arbitrary limited by the number of COEs (permits) allowed by the government. After 10 years, the vehicle has to be scrapped. In spite of the fact that the vehicle may

have a longer lifespan, the vehicle must either be disposed of, or renewed at prevailing COE rates. A vast majority have exercised the option of scrapping their vehicles. Economic variables, such as income play almost no role in the growth rate of vehicles. Evidence that demand for vehicles always outstrips supply of COEs supports this¹⁵. The model is now constructed. Data on car population from end 2009 will be used, and utilizing the various variables, some estimated, a

model which replicates population data from end 2009 – end 2014 will be done, and simulation until end 2019 will be done, The value of interest here is the vehicle population at the end of the year 2015, which will be utilized in models to follow.

The model is as follows:



Model 2: Model of Car Ownership in Singapore

Certain variables where defined equations are not available was constructed using historical data. For instance, the rate of vehicle de-registrations was obtained from using 5-year historical data of vehicle de-registrations, and an average rate was computed to be approximately 3%.

Unallocated quota is set to be zero because when the growth rate is set, regardless of whether the allocated quota is fully utilized, it will be brought forward to the following year. For instance, if car

population is 100, at a growth rate of 3%, in time $t=1$, the population will be 103. Assume 2 quotas are used, 1 was not. In time $t=2$, car population will be $(103 \times 103\%) = 106$ vehicles. The same value is obtained if the utilized COEs grow at 2%, and unallocated quota is brought forward, i.e. $(102 \times 103\%) + 1 = 106$. As such, unallocated quota is already factored in via the growth rate. Also, the yearly unallocated quota is small and when combined, averages around 1000 COEs a year.

¹⁵ Fwa, TF. 2005. 'Sustainable Urban Transportation And Planning: Issues And Challenges For Singapore'. National University of Singapore.

Another factor to note of the model is the projected vehicle de-registrations. COEs allow ownership of a vehicle for 10 years. The model predicts that 40% of the number of vehicles registered 10 years ago will be de-registered, while the remainder will be renewed. Data of registrations from 1999 – 2009 are utilized using the lookup function.

The projection error accounts the error made by the Land Transport Authority when projecting the amount of de-registrations. Recall that the COE quota for a particular year is also partly determined by what the LTA projects deregistration for that same year to be. We estimate that the LTA projects the vehicle deregistration to be 80% of what actual yearly deregistrations are.

A table comparing results from the model and actual data is as follows:

End of Year	2009	2010	2011	2012	2013	2014	2015
Model Data	925518	941250	956446	967509	972447	973155	971886
Actual Data	925518	945829	956704	969910	974170	972037	---

Table 4: Table of Model and Actual Data of the Car Population Model

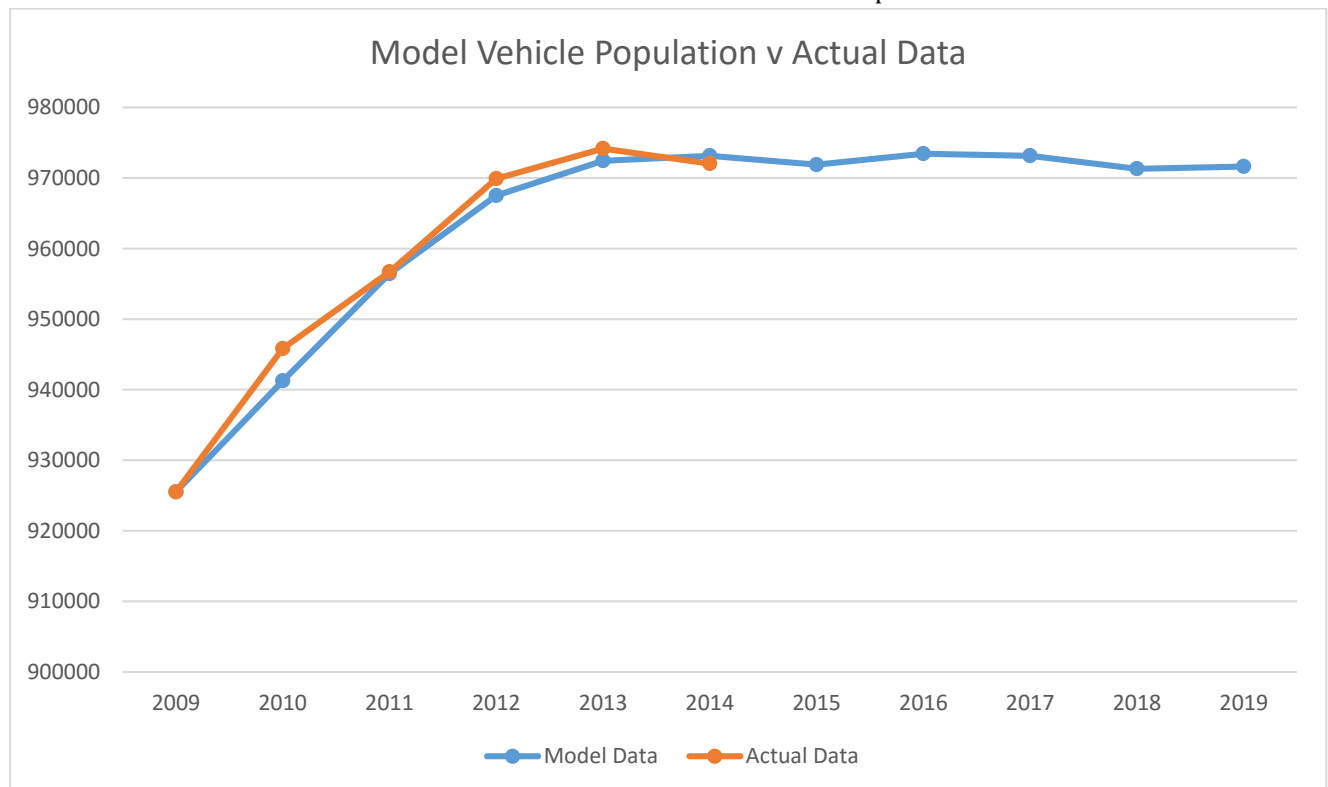


Figure 2: Plot of model vehicle population v actual vehicle population

It is observed that the actual vehicle population varies slightly from the population predicted by the model. However, the prediction is always within a 1 – 2% deviation of the actual result – a negligible deviation.

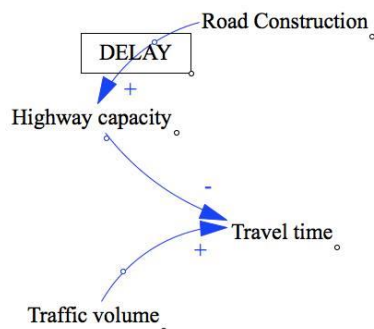
The model also predicts that the number of vehicle registrations will taper off beyond 2014. This is consistent with the Transport Ministry's

intention of reducing car population growth to zero¹⁶ - confirming the validity of the model.

3.2 The Traffic Flow and Time Travel Index (TTI) Model

This paper will now model Singapore's traffic congestion problem by determining a travel time index (TTI). A good basis to start modelling will be to look at existing literature regarding the fundamentals of modelling.

Sterman in his book *Business Dynamics* provides some mental models of traffic congestion. Average travel time is a good summary measure of congestion – and is determined by the balance between road capacity and average number of vehicles using the roads. He presents the following model for consideration:



Model 3: Mental Model of Travel Time Proposed by Sterman

An increase in road construction increases highway (or road) capacity, while a higher number of cars (traffic volume) will increase travel time. Congestion is deemed to occur when travel time exceeds typical average travel times.

The model presented in this paper will also use travel time as an indicator of congestion level.

Does Congestion Exist in the First Place?

We also need to determine whether congestion is present in Singapore. One of the determinants is free flow speeds during peak hours. The Land Transport Authority provides average traffic flow speeds during peak hours for the past 10 years:

Year	Average Speed During Peak Hours (km/h)	
	Expressways	CBD/Arterial/Local Roads
2005	62.8	26.7
2006	62.7	27.6
2007	61.2	26.8
2008	63.6	26.6
2009	62.2	27.6
2010	62.3	28.0
2011	62.5	28.5
2012	63.1	28.6
2013	61.6	28.9
2014	64.1	28.9

Source: Land Transport Authority, 2014

* Speeds were calculated as an average of AM Peak and PM Peak hours (8a.m. – 9a.m., 6p.m. – 7p.m.)

Average speed limits for expressways and CBD/arterial roads are at an average of 90 km/h and 60km/h respectively. Following the definition for traffic congestion presented earlier, congestion occurs when free flow speeds are 70% of the speed limit. That is, congestion occurs when average speeds are at or below 63 km/h and 42 km/h respectively. We can see the range of speeds fluctuating from 61.2 – 64.1 km/h and 26.6 – 28.9 km/h for expressways and CBD/arterial roads respectively.

Following our definition, traffic congestion occurs during peak hours in Singapore. The sufficient condition exists.

¹⁶ Tan, Christopher. 2015. 'Zero Car Growth 'Likely In Future''. Asiaone.

<http://news.asiaone.com/news/singapore/zero-car-growth-likely-future>

The Model

As noted earlier, the model will determine the additional time required to travel in the event of congestion. We define a new factor, called the **travel time index (TTI)**. We define travel time index with the following equation:

$$\text{Travel Time Index (TTI)} = \frac{\text{Time Taken with Congestion}}{\text{Time Taken at Free Flow Speeds}}$$

GPS data determines that the 13.1 km journey from Bedok to the CBD will require 20 minutes at normal free flow speeds (that is, at the speed limit of each road). When we divide the time taken with congestion with 20 minutes, we will obtain the travel time index. The travel time index indicates how many multiples of the original time taken is required to commute in the event of congestion.

For instance, a TTI of 1.5 indicates that in the case of congestion, it will require 1.5 times the normal time to travel to the same location, due to reduced speeds on the road. We would expect the model to produce a TTI of greater than 1.

Volume of traffic will be measured by vehicle-kilometres per day, which is, the total distance travelled by all vehicles in one day. This can be explained by the following equation:

$$\begin{aligned} \text{Vehicle Kilometres per Day} \\ &= \text{Number of Vehicles} \\ &\quad * \text{Average Trips per Day} \\ &\quad * \text{Average Distance per Trip} \end{aligned}$$

We will define the 3 variables in the equations as follows:

- Number of Vehicles:
963746 (prediction of model in 2014)
- Average Trips per Day:
Contingent on five factors:

- Enforcement of ERP system
- Public transportation price level
- Occupancy of public transportation
- Parking capacity
- Fuel subsidies

All these factors will be explained later, when producing the model

- Average Distance per Trip:
13.1 km (distance from Bedok to the CBD area)¹⁷

Model Assumptions & Facts

The following are some assumptions and propositions made in order to produce the model:

- 1) Singapore is always working. That is – in this model, every period is rush hour – where traffic is the heaviest. As we are only interested in simulating congestion, we will not attempt to produce a model with normal traffic conditions. Also, data on average speeds during normal periods are not available as well – which makes creating the simulation not worthwhile, as there is no metric for comparison. The AM peak and PM peak periods are treated as a continuous time period – which is reasonable, as we would expect the same users of the AM peak rush to return home during the PM peak.
- 2) We treat the number of vehicles as a given (that is, it does not change). This is such, as we do not reasonably expect the population of vehicles to grow within such a short span of time (2 hours). A model of the vehicle population has also been constructed and simulated in the previous section. We also hold all other factors constant. We will change this later on, for the purpose of using policy levers.

¹⁷ Of all townships in Singapore, Bedok is the most densely populated (almost 10% of resident Singaporeans stay here),

and hence, is used as the mode starting point of travel. (Source: Census of Population 2010, Singapore)

- 3) There exist many types of vehicles of different sizes, which will be classified into 3 main categories:
 - i) Cars (includes taxis)
 - ii) Motorcycles
 - iii) Heavy vehicles (includes buses, lorries and trucks)
- 4) Each category of vehicle takes up different amounts of space on the road. To account for this, we define the Passenger Car Unit (PCU) equivalent. A car has a PCU of 1 (that is, a car has a passenger car unit equivalent of 1), a motorcycle has a PCU of 0.5 (1 motorcycle takes up half the space a car does on the road), while a heavy vehicle has a PCU of 2 (2 cars = 1 heavy vehicle). To simplify matters, the unit of account of PCU will be vehicles, as intuitively, a heavy vehicle counted as two “vehicles”, makes sense.
- 5) When thinking of traffic congestion – what also becomes significant is the number of vehicles which comes in from Malaysia. Singapore’s situation is unique in the sense that entry of vehicles from Malaysia is significant, relative to other countries, as the state of Johor Bahru, Malaysia is separated from Singapore via a short 1.1 kilometre causeway. Approximately 9 million trips were made by Malaysian vehicles to Singapore every six months, or 50,000 per day.¹⁸ 80% of these trips are made for a one day duration only, that is, the vehicle comes in from and returns to Malaysia in the same day. It can be safely assumed that these vehicles are used by Malaysians working in Singapore to commute to their workplace in Singapore. As such – it is deduced that 40,000 vehicles enter Singapore from Malaysia on each working day. This amount will be added to the vehicle population in Singapore

- 6) The breakdown of the vehicle population in Singapore is as follows¹⁹:

a. Cars	66.64%
b. Motorcycles	14.90%
c. Heavy Vehicles	18.46%

Of the 40,000 vehicle entries from Malaysia - 67% are motorcycles, 24% are cars and 9% are goods vehicles and buses. After taking this into account, the composition then becomes:

a. Cars	64.94%
b. Motorcycles	17.00%
c. Heavy Vehicles	18.06%

- 7) Given that we are holding every variable constant, the travel time index simulated will also be a constant, and for now, will not affect the average trips per day.
- 8) A rational driver will aim to minimize travel time and search for the quickest route. Road users, noticing increasingly congested limited-access roads (expressways) and main roads will shift to using alternative roads, such as smaller roads. Traffic will move between these two roads until the travel time on both these roads are approximately at equilibrium. That is, there will be no additional benefit of utilizing either road ²⁰. Given this, we will collectively assume that main roads, expressways and local roads (i.e. all roads) carry the same purpose of being the road used by a road commuter to commute from home to the CBD and back.

There are also numerous other factors created to construct the traffic model, some of which are specific to the context of Singapore. They are explained here:

¹⁸ Facts obtained from parliamentary question answered by Former Transport Minister Lui Tuck Yew on 12 August 2013.

¹⁹ Data from Land Transport Authority, 2015

²⁰ Downs, Anthony. 1992. Stuck In Traffic. Washington, D.C.: Brookings Institution.

1. **Vehicle use rate** - not all vehicles are used during peak hours. However, peak hours are the times where most vehicles are used. We will assume that 50% of the motor vehicle population is on the road during peak hours (the 50% unused vehicles could presumably be owned by workers who are ill, on leave, households who have two cars, who prefer to use public transport etc. and hence, are unutilized). This will be the baseline number – and is factored in as “Vehicle Use Rate” in the model – an exogenous constant. This will be used as a policy lever in the next section.

2. The earlier mentioned 5 variables which affect **Average Trips per Day**:

- **Enforcement of Electronic Road Pricing (ERP) System** – The ERP is a toll levied on vehicles entering the CBD area during peak hours – with the aim of limiting vehicle entry to the city during peak periods. There are a total of 77 ERP gantries in Singapore. This greater the enforcement of the ERP system, the lower the average trips per day. This will be utilized as a policy lever in the next section.
- **Price of public transportation** – Higher prices for public transport will increase attractiveness of driving, or taking road vehicles (i.e. taxis), which increases the average trips per day. This will be used as a policy lever later.
- **Occupancy of public transportation** – a factor to allow perception of drivers to public transportation. If public transportation is seen to be at overcapacity, private vehicles (including taxis) will be utilized to a greater extent. This also affects average trips per day. This factor is exogenous and estimated, and will be used as a policy lever in the next section.

- **Parking capacity** – greater ease of finding a parking spot will increase average trips per day.
- **Fuel subsidies** – prices in Singapore’s fuel market is determined solely by the market with no direct intervention from the government. This will be used as a policy lever later on.

All the above mentioned variables will have values of 1, and are linearly related to Average Trips per Day. The following table defines their relationships:

Variable	Relation	Value
Enforcement of ERP	-	1
Price of public transport	+	1
Occupancy of public transport	+	1
Parking capacity	+	1
Fuel subsidies	-	1
TOTAL TRIPS PER DAY	+	3

In the following section, these factors will be used as policy levers in order to alter the frequency a driver drives per day.

3. **Road closure factor** – proportion of roads closed for events or other seasonal purposes. More roads closed results in lower usable road-lane kilometres. This factor is estimated, and it is assumed that 98% of roads are usable at one point in time.
4. **Proportion of collector roads** – Collector roads are primarily built to feed traffic from local onto arterial roads. Collector roads are generally used by commuters going short distances, likely from their housing to the nearby market. Collector roads take up about 18% of Singapore’s total usable road kilometres. They are deducted from the

usable-road lane kilometres, as they are not used when commuting from a residential area to the CBD.

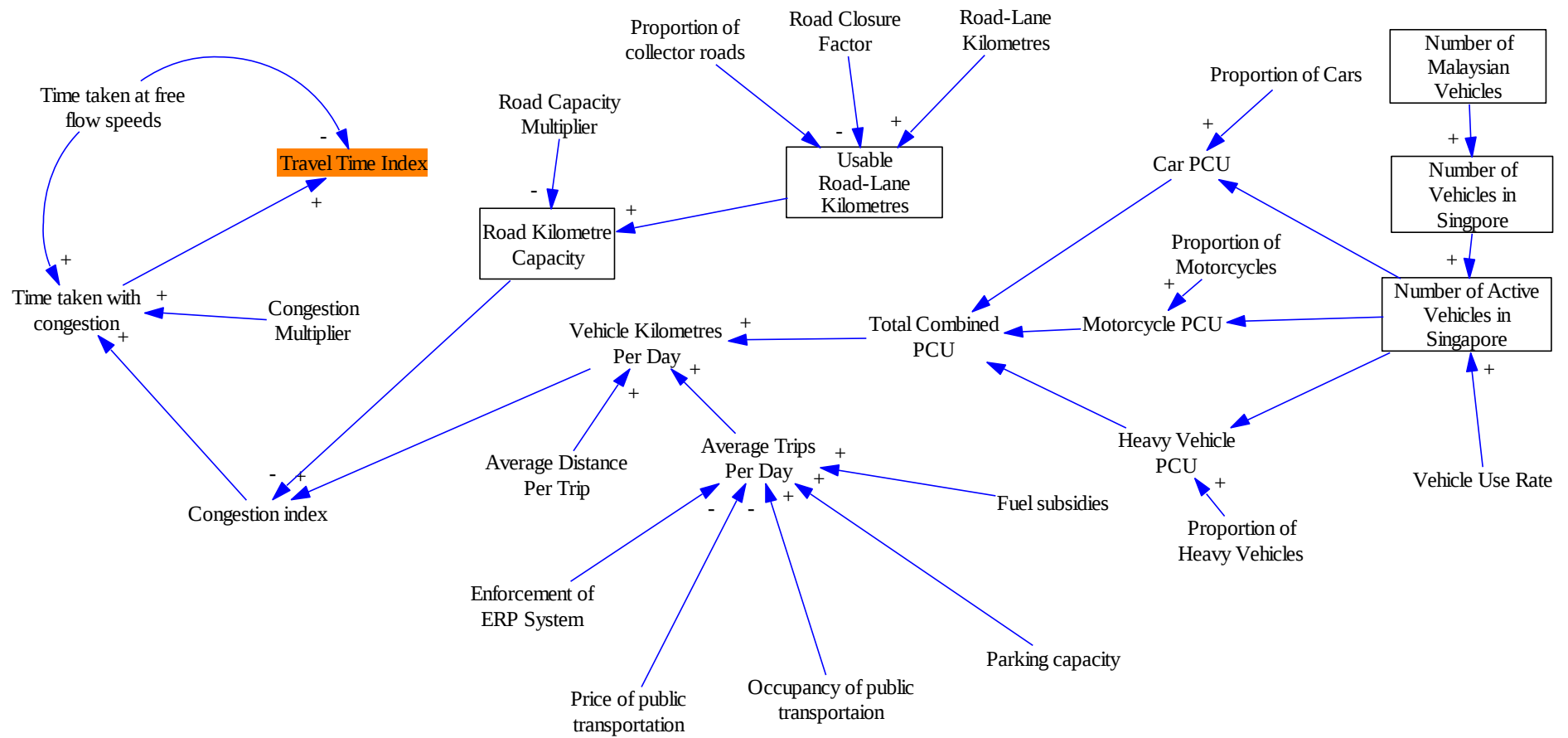
5. **Road Kilometre Capacity** – The “Usable Road-Lane Kilometres” factor does not determine the number of cars that a kilometre of road can accommodate. Road Kilometre Capacity is introduced to produce an intermediate variable that determines actual vehicle capacity. The variable is obtained by dividing Usable Road-Lane Kilometres with the **road capacity multiplier**. We assume that a kilometre of road can accommodate 20 vehicles moving at free flow speeds, that is, the road capacity multiplier is 0.05.
6. **Congestion index** – this is defined as Vehicle kilometres per day divided by Road Kilometre Capacity. It will be used as a numerical index of congestion – where a higher value indicates more severe congestion. It has units of vehicles/day. The value on its own carries no specific interpretation.
7. **Congestion multiplier** – this is a dimensionless variable that factors in the increased travel time per additional vehicle on the road. We define that every additional vehicle on the road beyond the road kilometre capacity will increase travel time by 0.05 minutes (3 seconds).
8. **Time taken with congestion** – This is defined as Time taken at free flow speeds + (Congestion index * Congestion Multiplier). A greater congestion index increases the time taken with congestion.
9. **Time taken at free flow speeds** – This is 20 minutes – the travel time between the township of Bedok and the CBD.

It is also noted that the variables denoted in boxes represent stocks but in our simulation, they are held constant.

Other variables carry their named meanings.



Figure 3: The PM rush hour peak in Singapore



Model 4: Model Predicting the Travel Time Index (TTI) of Singapore's Traffic Situation

The model determines the Travel Time Index to be **1.36109**, that is, during rush hour, a commute which is supposed to require 20 minutes will now take **27.2218 (≈ 27 minutes) per person per day**.

We can repeat this simulation for travel times from different housing estates in Singapore to the city. Among the other most densely populated areas are;

Area	Population (persons)	Distance from CBD (km)	Travel time at free-flow speeds
Jurong West	271,930	21.1	27 mins
Tampines	258,810	20.7	23 mins
Woodlands	250,180	12.5	16 mins
Hougang	219,440	11.0	17 mins

Table 5: Selected townships in Singapore with their respective populations, distance from CBD and travel time at free-flow speeds

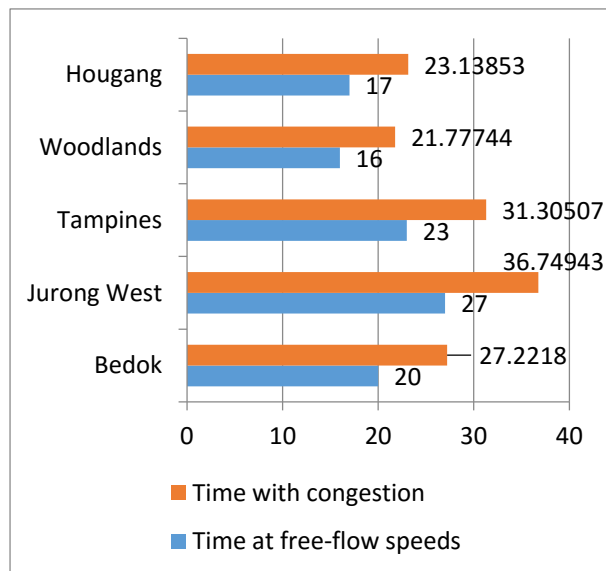


Figure 4: Estimated travel times with and without congestion

3.3 The Singapore Economy Model

To model Singapore's economy – we rely on one of the most fundamental and widely-known

economic production functions, the Cobb-Douglas economic production function.

The Cobb-Douglas function can be defined by the following equation:

$$Y = AL^{\beta}K^{\alpha}$$

- Y: total economic output (i.e. GDP)
- A: total factor productivity
- L: labour input (total number of hours worked in a year)
- K: capital input (real value of all machinery, equipment and buildings)

α and β are output elasticities of all capital and labour respectively

Simply put, α and β are responsiveness of economic output to increases in each unit of capital or labour. For instance, if β is 0.4, an increase of labour input (L) by 1 unit will cause Y (GDP) to increase by 0.4 units. The sum of $\alpha + \beta = 1$.

However, the point that is to be put across is that the model to be produced will include 2 basic inputs – labour (L) and capital (K).

We further note that traffic congestion does not affect capital productivity, but affects labour productivity. As such, we set $\alpha=0$. Our Cobb-Douglas function further simplifies to:

$$Y = AL^{\beta}K^{\alpha}$$

$$Y = AL^1K^0$$

$$Y = AL^1(1)$$

$$Y = AL^1$$

$$Y = AL$$

That is, economic output is contingent only labour input, and factor productivity. We will ignore factor productivity and will assume it to be constant. To factor in changes in the labour force, we also present a simple population model along with the economic model.

The model is simulated on a **daily basis**, and includes the following factors and variables:

1. Singapore Population

Changes in population are determined by the four flow variables:

- Births
- Deaths
- Immigration
- Emigration

The respective annual rates are obtained from Singapore Statistics. The Population White Paper also provides extensive information on number of work permits, PRs and citizenships offered each year. These rates and data are divided by 365 to obtain the daily rate.

The initial value is the population at the end of 2014, that is, the final value simulated will be the population at the end of 2015.

2. Economic Output per Capita per Day

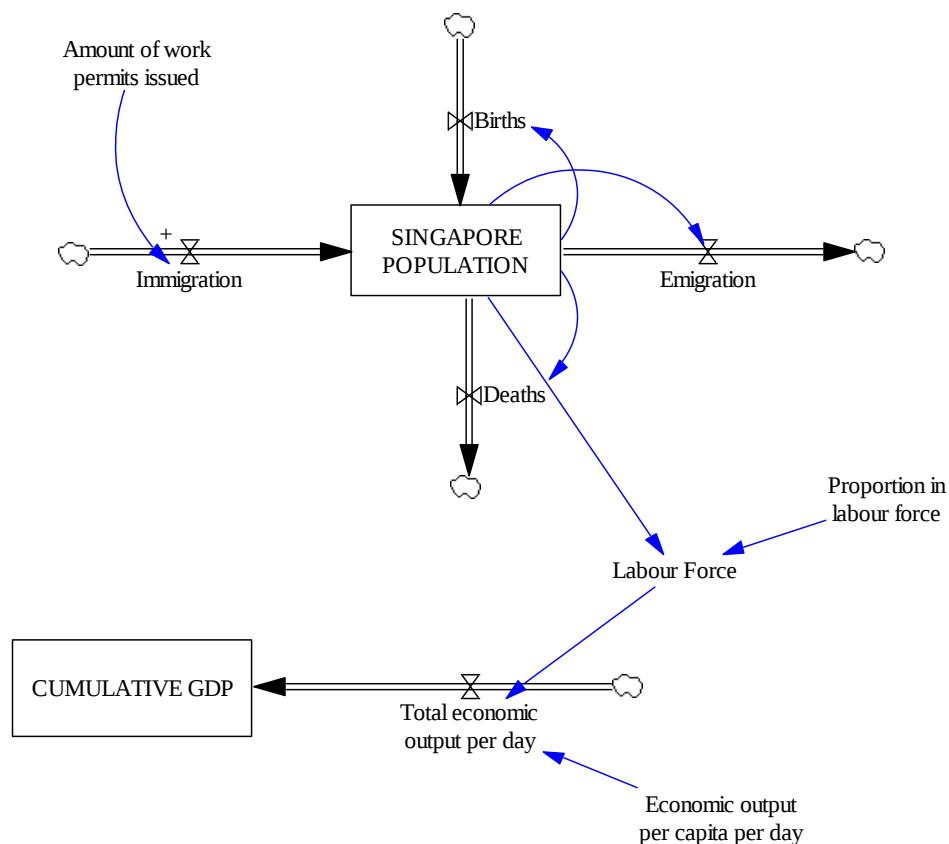
This value is obtained from the GDP per capita (SGD71317.90), and divided by the labour force participation rate (0.67). That is, we now spread total GDP of the country over the labour force instead of the entire population. This comes to SGD106444.63 per unit of labour, or SGD291.63 per unit of labour, per day.

3. Total Economic Output per Day

This is total labour output by the labour force per day. Is it obtained by multiplying the labour force with Economic Output per Capita per Day

4. Cumulative GDP

This is the sum of daily GDP for 365 days. This is simply the annual GDP output of the country. Cumulative GDP is simply Total Economic Output per Day multiplied by 365 days.



Model 5: Singapore Economy and Population Model

Simulating the model yields the following:

The model (for 2015) predicts these numbers:

GDP: SGD 397.868 billion
Population: 5.55354 billion people

Actual data from 2014 was:

GDP: SGD 390 billion
Population: 5.4697 billion

The year-to-year growth rates were:

GDP: 2.01744%
Population: 1.01201%

This seems to be reasonable year-to-year growth.

Although population growth forecasts are unavailable, the Ministry of Trade and Industry forecasted Singapore's 2015 GDP growth to be between 2.0% and 2.5%. This model seems to reflect the GDP growth rate well ²¹.

3.4 How Congestion Affects the Economy

In order to identify the economic cost of Singapore's traffic congestion problem, we need to know how congestion actually affects the economy. We can split this into three:

Individuals:

- Time lost in traffic jams
- Vehicle operation costs (fuel)

Businesses:

- Worker productivity loss (factored in under time lost)

Country:

- Environmental costs

We will introduce these variables into the model to mathematically determine the economic loss.

1. Time lost in traffic jams

As earlier determined, in the presence of traffic congestion, the travel time index (TTI) is 1.36109. What previously required 20 minutes to commute now requires over 27 minutes.

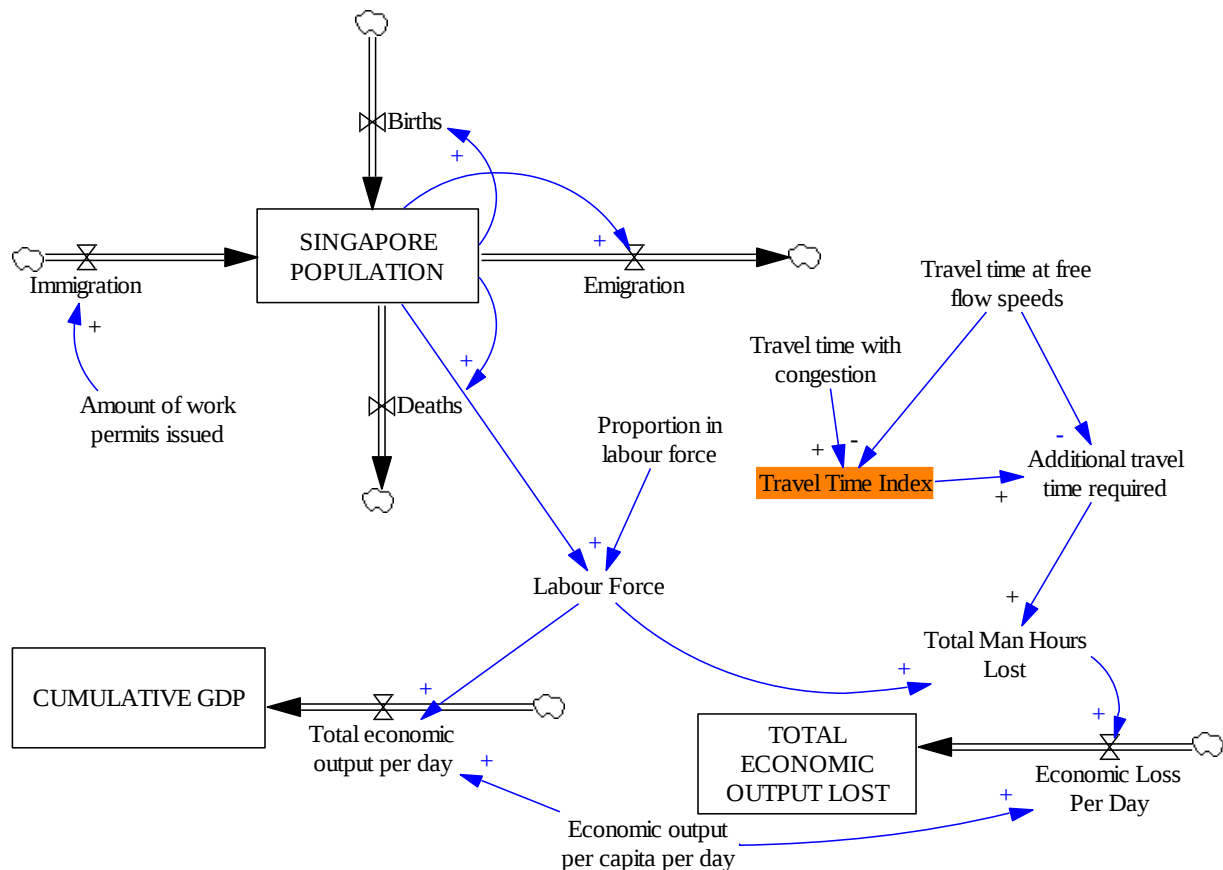
Road users, over time will take notice of this, and start to factor in additional time to arrive to their workplace in order to arrive on time. If we take into account that at least half the additional 7 minutes of travelling time (which is commonly referred to as buffer time) could be used for economically productive tasks, we can posit that 7 minutes per person per day is lost as "economic activity time" due to being stuck in congestions (3.5 minutes to work and 3.5 minutes coming back from work).

The population and economy model is now merged with several factors in the traffic flow model. The following model is derived. The simulation is run for a period of 365 days (i.e. start of 2015 – end of 2015). The stock Total Economic Output Lost is the aggregate of Economic Loss per Day for 365 days.

We note the following results simulated from the model:

- a) Total man hours lost per day is **18379 hours** on the first day of the simulation, and grows to **18599.7 hours per day** on the final day of the year (Additional travel time multiplied by the growing labour force)
- b) Estimated total economic output lost per day starts at **SGD5.434 million** and grows to **SGD5.499 million**
- c) Estimated economic output lost per year is **SGD1.99536 billion**

²¹ Ministry of Trade and Industry Singapore., 2015. MTI Narrows 2015 GDP Growth Forecast To 2.0 To 2.5 Per Cent.



Model 6: Economic Output Lost as a Result of Time Wasted in Traffic Congestions

2. Vehicle Operation Costs (fuel)

Persistent starting and stopping of the vehicle causes increased fuel consumption. This section will estimate fuel costs as a result of idling and moving slowly in traffic.

From the travelling time of 26 minutes, we assume that 13 minutes is spent idling or moving slowly, while 13 minutes is spent moving at free-flow speeds. Statistics show that an average mid-sized sedan car ²² consumes 0.279cc of fuel per second, 16.74ml per minute or 1.004 litres per hour when idling ²³. We assume that this is the same amount consumed when the car is moving slowly.

From the above, fuel wasted from not travelling at free flow speeds comes to:

$$\begin{aligned} \text{Fuel wasted} &= \frac{13}{60} \text{ hours} * 1.004 \frac{\text{litres}}{\text{hour}} \\ &= 0.21762 \text{ litres} \end{aligned}$$

This is the quantity wasted for a one-way journey. To-and-fro, 0.43524 litres of fuel are wasted.

With an average fuel cost (regular grade) of SGD2.08 per litre, fuel wastage of one vehicle per day is **SGD 0.9053** per vehicle²⁴.

²² An average sedan car is defined as a 2011 Ford Fusion with a 2.5L engine

²³ Office of Energy Efficiency & Renewable Energy, 2015. 'Fact #861 February 23, 2015 Idle Fuel Consumption For Selected Gasoline And Diesel Vehicles | Department Of Energy'. <http://energy.gov/eere/vehicles/fact-861-february-23-2015-idle-fuel-consumption-selected-gasoline-and-diesel-vehicles>.

[february-23-2015-idle-fuel-consumption-selected-gasoline-and-diesel-vehicles](http://energy.gov/eere/vehicles/fact-861-february-23-2015-idle-fuel-consumption-selected-gasoline-and-diesel-vehicles).

²⁴ Note that vehicle here refers to the passenger car equivalent (PCU) unit of account. It is assumed further that one motorcycle takes up half the fuel of a compact sedan, and a heavy vehicle consumes twice the amount of fuel.

Multiplying SGD0.9053 with total PCU (549,852 vehicles), obtained earlier, we see that total fuel costs is roughly **SGD 497,781.02** annually. 239,317 litres of fuel are wasted yearly.

We notice that the equivalent cost in the U.S. is much different. Different reports indicate that fuel wastage in the United States varies from 7.19 billion litres to over 100 billion litres^{25, 26, 27}. An analysis of these studies will provide an insight of the disparity in results.

Firstly, the basis of study is different. The results reported carry the assumption that **every vehicle** in the United States idles for approximately 15 minutes per day. In 2012, there were over 253 million registered vehicles in the U.S. – over 430 times more than the amount in Singapore²⁸. Besides, this paper carries the assumption that only vehicles being used during peak hour congestions contribute to the fuel wastage – this is about 50% of the total vehicle population in Singapore. The numbers obtained through this exercise is bound to be smaller than in the case of the United States.

Secondly, fuel wastage of increased acceleration were ignored in this estimation exercise, as estimating the wastage is mathematically difficult. A rough estimate of this can be included by increasing the assumed time spent idling and moving slowly. We assumed that in the 26 minute journey, 13 minutes are spent idling or moving slowly – that is half the amount of travel time.

Thirdly, a majority of U.S. loss comes as a result of the inefficiency of U.S. road transport infrastructure. The United States government allocated about 2% of its Federal budget on transportation in 2014, whereas Singapore allocated 6%, and is expected to spend up to 10.9% in the year 2015²⁹. Infrastructure defects, such as bottlenecks, unpaved roads and poorly defined road markings all contribute to the causing vehicle flow inefficiencies, contributing further to the congestion problem in the U.S. Reports also indicate that over 25% of highways, which carry 53% of kilometres travelled in the U.S. are poorly maintained³⁰. Rankings by the World Economic Forum also places Singapore placed 6th for quality of roads, while the United States ranked 16th.³¹ Poor road quality is a main factor to explain why the U.S. suffers a much greater wastage of fuel in congestion relative to Singapore, which has far superior road transport infrastructure.

3. Environmental Costs

The environmental cost of traffic congestion can best be quantified using carbon dioxide (CO₂) emissions. From earlier, the same assumption that a heavy vehicle emits twice the amount of emissions as a mid-sized sedan, and a motorcycle half that amount is carried forward here.

The nature of carbon dioxide emissions is unique in the sense that at different speeds, the

²⁵ U.S. Department of the Treasury,. 2012. Investments In Transportation Projects Create Jobs In Sectors Where Nearly 90 Percent Of Jobs Have Middle-Class Wages.

²⁶ International Road Transport Union,. 2015. 'IRU - Congestion Is Responsible For Wasted Fuel'.
https://www.iru.org/en_policy_co2_response_wasted.

²⁷ U.S. Federal Highway Administration,. 2015. 'Congestion Pricing - A Primer: Overview - The Congestion Problem'. Accessed November 11.
http://ops.fhwa.dot.gov/publications/fhwahop08039/cp_prim1_02.htm

²⁸ U.S. Department of Transportation,. 2014. Transportation Statistics Annual Report 2013. Washington D.C.: Bureau of Transportation Statistics.

²⁹ InsideGov,. 2015. '2015 United States Federal Budget'.
<http://federal-budget.insidegov.com/l/118/2015-Estimate>

³⁰ TRIP,. 2015. Bumpy Roads Ahead : America's Roughest Rides And Strategies To Make Our Roads Smoother. Washington D.C.

³¹ World Economic Forum,. 2014. *The Global Competitiveness Report*. Geneva: World Economic Forum.

amount of CO₂ produced through engine combustion is different.

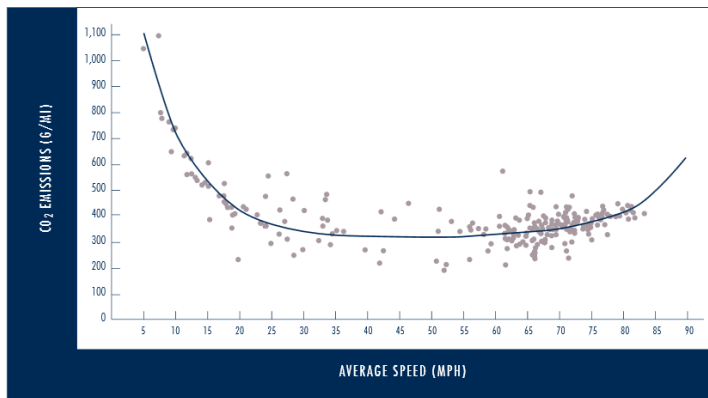


Figure 5: Graph indicating amount of carbon dioxide emissions at different speed ranges

At this point, it would be good to bring in statistics on vehicle speeds during peak hours as well. We note the following:

CBD/Arterial/Local Roads	28.9km/h
Expressways	64.1km/h

Table 6: Speeds at congestion

It will also be a good idea to bring in the distribution of all roads into the study. The total road-lane kilometres for expressways and arterial roads are:

Total Road-Lane Kilometres	
CBD/Arterial/Local Roads	4391 km
Expressways	3146 km

Table 7: Total Road-Lane Kilometres by Road Type

From our traffic flow model, we predicted that a total of 2.1609 million kilometres are made every day, and we take that the distance travelled on each type of road is in proportion to its road length.

³²Barth, Matthew, and Kanok Boriboonsomsin. 2008. 'Real-World Carbon Dioxide Impacts Of Traffic Congestion'. Transportation Research Record: Journal Of The Transportation Research Board 2058: 163-171. doi:10.3141/2058-20.

Total Vehicle Kilometres Travelled On...

CBD/Arterial/Local Roads	1.2589 million km
Expressways	901,965,77 km

Table 7: Total Vehicle Kilometres Travelled Based on Road Type

Singapore's total daily CO₂ emissions from vehicles can now be roughly estimated. The following data of CO₂ emissions during congestions and at free-flow speeds is calculated, and the increased / (decreased) CO₂ emissions as a result of different speeds^{32, 33}.

Table 8: Increased/(Reduced) Emissions as a Result of Decreased Speeds

	Arterial/CBD /Local Roads	Expressways
Speeds at Congestion	28.9 km/h	64.1 km/h
Average Emissions with Congestion	310.6856 g/km	186.4114 g/hr
Free-flow speeds	60 km/h	90 km/h
Average Emissions at Free-flow speeds	186.4114 g/hr	192.6251 g/hr
Increased/(Reduced) Emissions	124.2742 g/km	(6.2137) g/km

Multiplying the increased / reduced emissions with the number of vehicle kilometres travelled, we get:

Type of Road	Total Increased / (Reduced) Emissions
Arterial/CBD/Local Roads	156448790.4 g
Expressways	(5604544.705) g
TOTAL	150,844,245.7g

Table 9: Total increased emissions due to reduced speeds

That is, congestion contributes an additional 150,844,245.7 grams of carbon dioxide daily. That is about 150.844 metric tons of carbon dioxide daily, or **55,058 metric tons** of carbon

³³ Office of Transportation and Air Quality,. 2014. Greenhouse Gas Emissions From A Typical Passenger Vehicle. United States Environmental Protection Agency.

dioxide yearly is produced as a result of congestion.

But how much does this cost to Singapore's economy? Increased air pollutants affect the air pollutant levels. High pollutant levels affect air quality, and bring about respiratory and health effects. Such effects affect the productivity of the labour force.

However, we note that the increased CO₂ emissions due to congestion only makes up 0.4% of Singapore's annual CO₂ emissions, which stands at 13,504,820 million metric tons. We also need to note Singapore's average air pollutant levels³⁴.

Singapore's annual PM _{2.5}	WHO interim target-2 (IT-2) ³⁵
12 µg/m ³	25 µg/m ³

Table 10: Singapore's annual PM_{2.5} against WHO standard PM_{2.5}

We can note that Singapore's annual PM_{2.5}, which is an index for pollutant particles in the air is much lower than the World Health Organization's level which reduces the risk of premature mortality.

As such, it will be posited that the additional emissions due to increased congestion, which makes up approximately 0.4% of Singapore's annual CO₂ emissions, a very small amount, and hence, does not cause any factor productivity loss to Singapore's economy.

3.5 The Total Economic Cost to Singapore's Economy

To summarize, in the preceding four sections (3.1 – 3.4), the following was done:

1. A model of Singapore's 2015 and subsequent year's car population was produced.
2. A system that determined the travel time index as a result of congestion was presented.
3. A model predicting Singapore's GDP and population at the end of year 2015 was made.
4. Costs as a result of congestion were calculated using the travel time index derived in section 3.4.

We can now calculate total economic loss as a result of congestion. We sum up the cost of lost travel time and fuel costs:

Factor	Total Cost
Time loss	SGD 1,995,360,000.00
Fuel wastage	SGD 497,781.02
TOTAL LOSS	SGD1,995,857,781.02

Table 11: Total economic loss to Singapore

As such, it is posited that traffic congestion during peak hours costs Singapore's economy SGD 1.99585778102 billion dollars in 2015, or equivalent to a cost of SGD 364.89 per capita.

We can contrast this to the loss in other countries, namely the United States, and United Kingdom.

³⁴ National Environmental Agency,. 2015. Factsheet On More Measures To Improve Singapore's Air Quality. Singapore: Ministry of the Environment and Water Resources.

³⁵ World Health Organization,. 2006. WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide And Sulfur dioxide. Switzerland.

Factor	Singapore	United Kingdom	United States
Gross Domestic Product (GDP)	SGD 390 billion	SGD 4.3 trillion	SGD 25.3 trillion
Population	5.4697 million	64 million	318.9 million
GDP per capita	SGD71317.90	SGD 67187.50	SGD 79355.21
GDP Loss Through Traffic Congestion	SGD 1.9958 billion	SGD 30.39 billion	SGD 177.84 billion
GDP Per Capita Loss	SGD 364.89	SGD 474.84	SGD 557.67

Table 10: Summary Table of GDP and GDP per capita loss resulting from congestion

We notice that the loss to Singapore is lower than the case in United Kingdom and the United States. The following reasons can possibly explain the smaller magnitude of loss to Singapore:

1) Efficiency of public transport

Singapore's public transportation network is consistently ranked as one of the best in the world³⁶ - characterized by high percentage of on-time arrivals and infrequent breakdowns. A widely available and accessible public transportation promotes high switching from private transport (vehicles) to public transport (mass rail transit, MRTs and high-capacity buses). If a motorist feels that the congestion causes their travel times to exceed what is beyond their tolerable amount of time, they may choose to switch to public transportation, thus reducing road congestion. The population of Singapore is also concentrated around specific townships, and the MRT system services all the townships. Upcoming extensions are also being proposed to further expand public transit ridership.

In contrast, the UK and the US are characterized with many little townships surrounding the many CBDs in the country. Mass transit systems cannot service every single one of these suburbs and townships, causing many to resort to private transportation. Large inflow of vehicles into

the CBD from surrounding townships causes congestion, which cannot be solved without expanding public transportation capacity and reach.

2) Fuel costs

This has been discussed earlier. The loss to the US has been exacerbated by the study methodology, which as mentioned earlier, the studies assumed all vehicles are used every day, while in this study, it was assumed that only half of all the vehicles in Singapore are being used.

Fuel costs also play a role in the final calculation of costs. In Singapore, average fuel costs in 2015 was SGD2.08, In the UK, the average 2015 fuel cost was SGD2.81. Higher costs can possibly contribute to an increased absolute value of GDP per capita loss due to congestion.

3) Environmental Costs

This paper has ignored the environmental costs and posited that emissions from vehicles did not affect the factor productivity of the Singaporean economy – that is, increased CO₂ does not affect the Singapore workforce, either through sicknesses or reduced vision etc. This is due to the fact that as earlier posited, Singapore's annual air pollutant index levels are well below international guidelines. Although certain

³⁶Sim, Royston. 2014. 'Study: Singapore's Public Transport System One Of World's Most Efficient'. The Straits Times. <http://www.straitstimes.com/singapore/transport/study>

[-singapores-public-transport-system-one-of-worlds-most-efficient](#)

shocks do affect Singapore's air levels – namely haze – a yearly phenomenon characterized by cross-boundary smoke blowing in from Indonesia, this is not resulting from traffic congestion from Singapore in any way. It is likely the other two studies factored in the effects of carbon emissions when calculating the corresponding economic loss.

3.6 Conclusion

The economic cost of congestion to Singapore is markedly less than in the United States and the United Kingdom. Several factors can explain this – considerably higher efficiency of public transport and its smaller geography with greater accessibility minimizes this cost.

Although smaller than the other two countries, an economic loss of SGD364.89 per capita, or SGD1.9958 billion per year is a number that should not be neglected. Overtime, with a growing population, we can expect a marked increase in the GDP loss.

There are, however, some arguments taking the viewpoint that congestion is necessary and is just a by-factor of rapid economic growth. This, alongside analysis of road congestion alleviation measures will be discussed in Section 4.

3.7 Limitations of the Model

As with most modelling practices, there are limitations to the model(s) presented here as well.

Firstly, a considerable amount of data had to be estimated. For instance, the amount of usable road-lane kilometres was taken as a constant, with the assumption of no further growth at all. Data on carbon emissions and fuel wastage involved studies on two different cars, and would not be representative of the average benchmark in Singapore (although finally, it was assumed

that air pollution did not affect Singapore's economic productivity).

Secondly, in the travel time index estimation, all factors were held to be constant, and a model of change in traffic population over time was not considered. It also assumed the travel time index to be a constant throughout the year, rather than a changing value which would factor in changes in the population and vehicle population.

Lastly, all relationships between the variables and factors in the model were taken to be linear, although there is a likelihood that certain relationships can be characterized with more complicated relationships. Linear functions were taken for the added convenience of simplicity.

The following section will analyse congestion reduction methods.

4. CONGESTION REDUCTION

Systems thinking requires analysis of a problem as a whole, and acknowledging that fixing the problem at one place may lead to a spill over effect into another part of the system. This section will attempt to use systems thinking and economic theory to analyse congestion reduction systems:

This section can be further divided into three subsections:

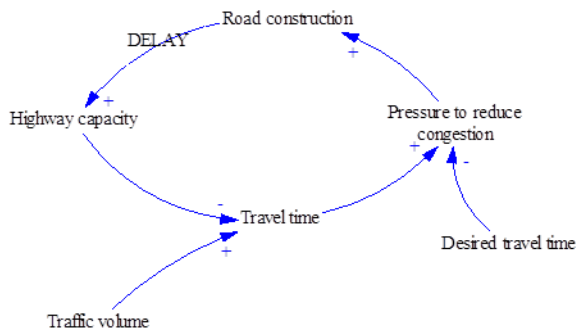
- Road System Improvements
- Restraint Measures
- Regulatory Approaches

4.1 Road System Improvements

Road system improvements largely fall on road capacity expansion, to increase the amount of usable roads.

Increasing Road Capacity

Sterman noted in his book *Business Dynamics* the following model:



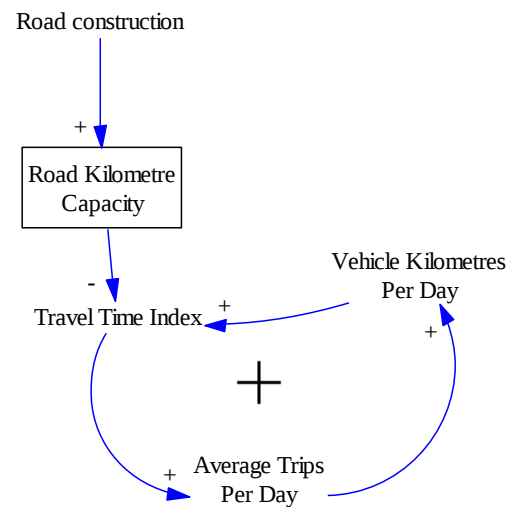
He noted that increased road construction will increase highway capacity, which will reduce travel time. When applied to our model, we can single out the Usable Road-Lane Kilometres. Increasing construction will thus increase highway capacity – with delay, as road construction projects generally take years to complete.

However, building more roads to increase capacity will inevitably increase the number of road users. This is known as the Pigou-Knight-Downs paradox – an economic paradox which states that improvements in traffic congestion will actually not improve traffic congestion, and in certain cases, worsen the situation. This is due to induced (latent) demand – where increase in supply inevitably causes a demand increase far greater than the supply increase.

Consider the following example. Heavy congestion leads to many rush-hour vehicle trips to be diverted to mass transit or road public transportation (buses). However, with road construction, there will be more roads which lead to the same destination, causing traffic to be inherently reduced. A commute time of 40 minutes now requires 30 minutes, for instance. Reduced travel times encourage people who

would not have previously commuted using their own vehicles to make the decision to travel by their own vehicles. Commuters who would not have used the road during peak hours will start to use the roads during peak hours. All this convergence leads to increased vehicle use rate, increasing the number of vehicles on the road and ultimately, the travel time index.

Consider a simplified portion of the Singapore model, factoring in road capacity expansion:



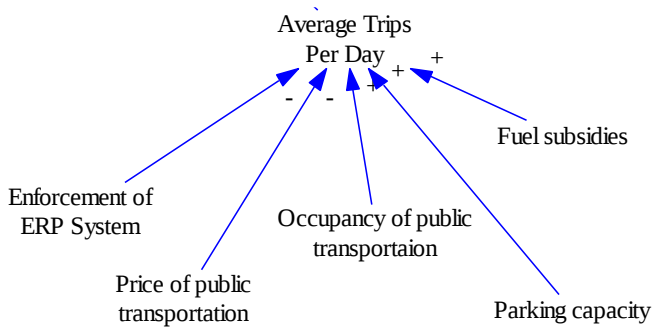
An increase in road construction will increase road kilometre capacity. More roads – at a fixed level of trips and vehicles, will reduce the travel time index.

However, a reduced travel time index will increase average trips per day, increasing the amount of kilometres travelled (Vehicle Kilometres per Day), thus increasing road use and travel time index (one reinforcing loop).

With any form of road expansion, the Travel Time Index will be at least as high as in the case with no road expansion at all.

An alternative paradox, the Downs-Thomson paradox, also states that investment in road capacity expansions also shifts investment away from other sectors in the economy. Disinvestment in other sectors, such as the public transport system will cause public transport quality degradation.

Recall from the traffic congestion model:



The Average Trips per Day variable, which can act as a proxy of driving attractiveness, is contingent on price and occupancy of public transportation. A disinvestment in public transportation (namely mass rail transits, MRTs) will force the operators of the train services, SBS and SMRT, which are semi-government assisted, to increase the price of public transportation fares in order to maintain its operations and profit margins. Reduced investment will also cause the companies to be unable to expand the capacity of its train carriages. For a given amount of passengers, reduced capacity means higher occupancy of public transportation.

Both factors will decrease the attractiveness of using public transportation, and increase the attractiveness of driving. This causes a greater congestion index, and increased travel time index on the road.

Both the Pigou-Knight-Downs and Thomson-Downs paradox highlights the inability of increased road capacity to ease road congestion. In the case of Singapore, with limited land and space for further road development, it is unlikely that road expansions will be used, also highlighted with the LTA announcing new roads will only be built to serve new residential areas³⁷.

4.2 Restraint Measures

Restraint measures have the aim to reduce vehicle usage. In the context of our model, we are looking at measures that will reduce Average Trips per Day.

Before we proceed into each individual factor, we need to make some alterations to our model. Recall that Average Trips Per Day is contingent on five factors.

- Enforcement of ERP system
- Price of public transportation
- Occupancy of public transportation
- Parking capacity
- Fuel subsidies

The relationship was earlier modelled as:

$$\begin{aligned}
 \text{Average Trips per Day} &= \text{Occupancy of public transportation} \\
 &+ \text{Fuel subsidies} + \text{Parking capacity} \\
 &+ \text{Price of public transportation} \\
 &- \text{Enforcement of ERP system}
 \end{aligned}$$

Where each of the factors have a value of 1. We now look at the three restraint measures from the list of 5 above:

1. Occupancy of public transportation
2. Price of public transportation
3. **Enforcement of ERP system**
4. **Fuel subsidies**
5. **Parking capacity**

Enforcement of ERP system

The enforcement of the ERP system is simply the total price paid to travel to-and-from the CBD. That is, the price charged per gantry, multiplied by the number of gantries passed by the motorist. To factor in the differing rates for cars, heavy vehicles and motorcycles, averages will be relied on. It will continually be assumed that the ERP charge for a motorcycle is half that of a car, and a heavy vehicle is twice that of a car.

³⁷ Land Transport Authority, 2013. Land Transport Master Plan 2013. Singapore.

Taking our “average” trip from Bedok to the Singapore CBD, the total ERP costs will be SGD 4.00, passing by two ERP gantries of each charging SGD2.00. When returning back to Bedok, total ERP costs will be SGD1.00, passing by two ERP gantries of each charging SGD0.50. Total ERP costs per day will be SGD6.00.

At a cost of SGD6.00 (the original fee), it was posited that the average trips taken per day is 3. It was also earlier noted that the Enforcement of ERP system factor equals to 1.

Factoring in the cost into the equation:

$$\begin{aligned}
 \text{Enforcement of ERP system} &= 1 \\
 \text{Enforcement of ERP system} &= \text{SGD6.00} * \text{factor} \\
 \text{SGD6.00} * \text{factor} &= 1 \\
 \text{Factor} &= \frac{1}{6}
 \end{aligned}$$

We can define the factor to be the sensitivity of a motorist to the price of the ERP. With every increased of price of SGD 1.00 in the ERP, the motorist will *reduce* her average trips per day by 1/6.

We then test the change of travel time index with increases in the price of the ERP. This is done by substituting the values into the traffic flow (travel time index) model:

Total Price of ERP	Travel Time Index
SGD7.00	1.34103
SGD8.00	1.32097
SGD9.00	1.30091
SGD10.00	1.28085
SGD11.00	1.26079
SGD12.00	1.24073

We can note that for every increase in the price of the ERP by SGD1.00 will cause the Travel Time Index to fall by 1.49%.

Fuel subsidies

Singapore’s fuel market enjoys no government intervention, that is, market forces (supply and

demand) dictate the price of fuel in Singapore. The government provides no subsidies at the moment.

The fuel subsidies factor was earlier defined to take a value of 1. That is, with no fuel subsidies, the factor fuel subsidies takes a value of 1. We use regular grade unleaded fuel as the benchmark, which through 2015 has an average price of SGD2.08 (as used in the earlier section).

$$\begin{aligned}
 \text{Fuel subsidies} &= 1 \\
 \text{Fuel subsidies} &= \text{Factor} * \text{Price of fuel} \\
 \text{Factor} &= \frac{\text{Fuel subsidies}}{\text{Price of fuel}} \\
 \text{Factor} &= \frac{1}{2.08}
 \end{aligned}$$

The opposite of a subsidy is a tax. The government can choose to impose tax on imported petroleum (Singapore does not produce petroleum) in order to increase its price.

$$\begin{aligned}
 \text{Fuel subsidies} &= (\text{Factor} * \text{Price of fuel}) \\
 &\quad - \text{Tax} \\
 \text{Fuel subsidies} &= \left(\frac{1}{2.08} * 2.08 \right) - \text{Tax}
 \end{aligned}$$

$$\text{Fuel subsidies} = 1 - \text{Tax}$$

We then test the change of travel time index with increases in fuel taxes by the government. This is done by substituting the values into the traffic flow (travel time index) model:

Fuel Tax	Travel Time Index
SGD0.20	1.33702
SGD0.40	1.31925
SGD0.60	1.28887
SGD0.80	1.2648
SGD1.00	1.24073
SGD1.20	1.21665

We can note that for every increase in fuel taxes of SGD0.20 will cause the Travel Time Index to fall by 1.329%.

Parking Capacity

Parking capacity is a lever that is difficult to alter in the short run. Construction projects with the aim to expand parking capacity require years to complete. Demolition of car parks is also unfeasible, as many motorists who travel to the CBD sign long-term agreements, better known as seasonal parking. It is also difficult for the government to impose limits on car park bays in the CBD area.

As such, parking capacity will be ignored as a policy lever to affect the average trips taken by a motorist per day. It will be assumed that parking capacity will remain constant in the short run.

Analysis of Restraint Measures

Restraint measures act like a form of Pigouvian tax. The Pigouvian tax is a tax applied to activities that generate costs to society (negative externalities).

As mentioned in the introduction to this paper, motorists, who ignore spill over effects tend to utilize their vehicles more than what is socially optimal. They ignore the consequences of their own action. Restraint measures will increase the costs the motorist bears.

Recall that a motorist will choose to commute by their own vehicle if its benefits exceed its costs. Restraint measures are meant to increase a motorist's costs beyond the benefits of commuting in a private vehicle. If a motorist's perceived benefit is less than the marginal cost, the motorist will take the additional ride.

As to whether increasing ERP fees or increasing taxes on fuel is the better measure, a two-pronged approach should be taken.

4.3 Regulatory Measures

Singapore enforces several regulatory measures to control the traffic population. Regulatory approaches involve making compulsory certain behaviours and prohibiting others.

The COE System

Based on the vehicle flow (TTI) model, the vehicle use rate was held as a constant, and only increases in vehicle population would increase the number of vehicles on the road.

Given the constraint on the model, the COE system would indeed be an effective system to continually limit the number of vehicles on the road, thus reducing the number of vehicle-kilometres travelled per day.

However, there have been arguments questioning the validity of the ability of the COE system to effectively control vehicle use rates. A tax on ownership, first of all, does not change the price of additional trips made in the vehicle³⁸. Others have also argued that usage taxes should be increased instead as it increases the price of trips. This is true as explained earlier – restraint measures increases the cost to the motorist, who will make decisions to drive after factoring in the relevant costs and perceived benefits. However, using the COE further allows the government to control the vehicle population, in addition to the restraint measures put into place.

The Weekend and Off Peak Car (OPC) Scheme

The Singapore government also implemented weekend cars and off-peak cars, which are demarked by red coloured registration plates. Such cars can only be used during post-peak hours on weekdays, and at any time on weekends. Such vehicles have lower COE prices, causing to lower costs to own such a vehicle.

³⁸ Chia, Ngee-Choon, Albert KC Tsui, and John Whalley..2003 Taxes and Traffic in Asian Cities: Ownership and use taxes on Autos in Singapore. No. 2003-

In the context of the vehicle flow (TTI) model, if the government maximizes efforts to make the weekend and off peak car (OPC) scheme more affordable and attractive relative to normal cars, we should see a marked reduction in the vehicle use rate. In this sense, the OPC can be viewed as a more effective control for congestion when contrasted to the COE system.

However, owners of OPC vehicles can still utilize their vehicle on weekdays given that they purchase a daily use permit. From an economics perspective, once again, we note that the motorist would only purchase the daily use permit if the benefit of using the vehicle on that particular day exceeds its cost. Once again, we notice that the factor being taken into account by the motorists is the cost of the trip rather than the cost of the vehicle. This brings us to the next section.

Why Restraint Measures are More Effective

This section will argue as to why restraint measures are more effective than a regulatory measure in limiting congestion. Two main factors describe the superiority of restraint measures.

Firstly, restraint measures can raise greater tax revenues for the government. Take into account, a fuel tax of SGD 0.40. Singapore's yearly import of petrol is roughly 62,279.9 kilo-tonne of oil equivalent (ktoe), and 14,322.8 ktoe of diesel. That roughly equates to 72,418 m³ and 14,615.1m³ of petrol and diesel respectively. If we are generous with our estimates and assume that 50% of these fuels are used by motorists, the Singapore government can raise over SGD17 million per year from a fuel tax alone. Regulatory measures only allow the government to collect a one-off fee during the purchase of the vehicle.

Secondly, restraint measures are much easier to enforce. The ERP gantries in Singapore uses short-range radio communication which deducts a fee from a vehicle's in-vehicle units (IVU). It is mandated by law that each vehicle is installed with an IVU. The ERP does not require

the vehicle to slow-down to pass the gantry, and can detect vehicles passing it at virtually any speed. When contrasted to enforcing the OPC scheme, which requires manual checks on daily use permits, the ERP is a much more efficiently enforced revenue-generating and congestion-regulating system.

However, a key nature of the two forms of measures is that they both are regressive. Restraint measures increases the cost of motoring to the low-income group, while regulatory measures increase the cost of vehicle ownership.

5. CONCLUSION

The following key figures were obtained through simulating Singapore's traffic flow situation:

Variable	Value
Travel Time Index with Congestion	1.36109
Economic Output Loss	SGD 1.9958 billion
Economic Output Loss per Capita	SGD 364.89

Singapore is a small but highly-developed economy, boasting some of the most efficient transportation systems in the world. It consistently ranks top in road transport network infrastructure, as well as public transport efficiency. It manages its vehicle population through tight regulatory measures, and has already laid out directions for what it intends to achieve within the next 15 years of urban transportation planning. With that said, although congestion is a problem that plagues many economies in the world, it does not seem to affect Singapore as much as it does other countries, for the reasons above.

Congestion, to a certain extent, is also favourable and welcome. As much as this sounds counterintuitive to whatever was mentioned in the previous 28 pages, congestion seems to be the symptom of success. In all major cities of the

world's largest economies, New York, Tokyo, New Delhi, and Beijing – all these cities suffer from congestion at much greater magnitudes than Singapore. High congestion is regularly associated with high economic activity. There is a saying that goes, "Congestion is a bit like cholesterol, if you don't have any, you die". In the context of Singapore, it seems to have much more good cholesterol than it has bad.

Singapore should maintain its current path in curbing congestion for it is currently outperforming many countries worldwide, and a large portion of it can be attributed to the country's relatively clean governance, and its small size allows easy and efficient implementation of policies.